THE JEFFERSON LAB QUALITY ASSURANCE PROGRAM FOR THE SNS SUPERCONDUCTING LINAC ACCELERATOR PROJECT*

Joseph P. Ozelis†, for the Jefferson Lab SNS Project Team
Thomas Jefferson National Accelerator Facility, Newport News, VA. 23606, USA

Abstract

As part of a multi-laboratory collaboration, Jefferson Lab is currently engaged in the fabrication, assembly, and testing of 23 cryomodules for the superconducting linac portion of the Spallation Neutron Source (SNS) being built at Oak Ridge National Laboratory. As with any large accelerator construction project, it is vitally important that these components be built in a cost effective and timely manner, and that they meet the stringent performance requirements dictated by the project specifications. A comprehensive Quality Assurance (QA) program designed to help accomplish these goals has been implemented as an inherent component of JLab's SNS construction effort. This QA program encompasses the traditional spectrum of component performance, from incoming parts inspection, raw materials testing, through to sub-assembly and finished article performance evaluation. Additionally, process and procedure control, vendor performance and oversight, and design and test program reviews constitute complementary areas where QA involvement contributes to successful production performance.

INTRODUCTION

The superconducting linac of the Spallation Neutron Source (SNS) will consist of 23 cryomodules. Eleven of these cryomodules will each contain 3 medium β superconducting RF cavities, with the remaining twelve each containing 4 high β cavities. In addition to superconducting cavities, the cryomodules contain tuner mechanisms, power couplers, diagnostic and control instrumentation, and cryogenic circuits.

These cryomodules must meet exacting performance requirements. To ensure this, a comprehensive Quality Assurance (QA) program has been developed. This program encompasses a wide array of activities and mechanisms, including:

- inventory control
- incoming component inspection
- component and materials testing
- vendor oversight
- process and procedure control
- process data capture
- process feedback
- sub-assembly test and measurement
- final assembly acceptance testing
- document control
- instrument and device calibration

Each of these independent yet coupled program elements is vital to ensuring that the cryomodules built by Jefferson Lab for the SNS SC linac achieve the required performance and reliability goals.

PROGRAM COMPONENTS

Inventory Control

All parts, components, and subassemblies delivered to JLab from vendors are inventoried, inspected for damage, and entered into a commercial electronic inventory tracking system. Components are identified using in-house generated bar code labels, and stored in a secure location. Access to component storage is restricted to authorized, trained personnel. Components that have not passed incoming inspection requirements (non-conforming parts) are segregated from usable inventory. This inventory control system ensures that accelerator components are carefully tracked, stored, and only acceptable components are used in cryomodule assembly.

Incoming Component Inspection

Where deemed necessary, dimensional inspections are performed upon receipt of a component to verify conformance with required parameters and tolerances. The inspections range from visual inspection to note the condition of surfaces, welds, or finishes, to precise geometric measurements utilizing a coordinate measuring machine (CMM) or surveying apparatus.

All inspections are performed using travelers or officially released drawings, and all inspection data is recorded electronically on-line via the travelers or generic inspection summary reports, using the *Pansophy* system [1], [2]. In the event that a component does not meet the required specifications, a non-conformance report (NCR) is issued and the item is returned to storage, tagged as "Do Not Use", and segregated from usable inventory, pending disposition.

Component and Materials Testing

In many cases, commercially purchased components or raw materials are tested for compliance with specifications. For the SNS medium β cavity production effort, essentially the entire inventory of high RRR Nb disks to be used for half cell fabrication was scanned for

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†ozelis@jlab.org.

defects using an eddy current apparatus [4], before being sent to the vendor. Niobium raw material was also tested for mechanical properties not only in the as-received state, but also after representative heat treatments.

Other components have also been tested to ensure adequate performance. High vacuum all-metal gate valves have been leak checked and tested for particulate generation. End cans, thermal shields, and other components of the cryogenic system are routinely leak checked.

Vendor Oversight

Vendor task execution is closely monitored so that uniform levels of quality performance are maintained throughout the production cycle. Vendor-supplied fabrication documentation and test reports are consistently reviewed and compared with in-house testing and verification of parameters to uncover discrepancies or breakdowns in the vendor's QA program. These are immediately addressed with the additional involvement of technical and procurement staff, and are often resolved through the adoption by the vendor of more accurate fabrication or testing procedures.

Process and Procedure Control

Consistent cryomodule performance relies upon the uniform and consistent application of processes and procedures that have been developed and refined through a comprehensive and exhaustive prototyping program. In order to provide this consistency, JLab relies upon process control documents, commonly called travelers, which guide all inspection, fabrication, and testing activities.

These travelers, which are all accessible in electronic form via a standard web browser from a server on the JLab intranet, provide detailed task instructions and links to procedures, reference drawings, and parameter lists, while also serving to provide "shop floor" oversight and review through process "hold-points". Currently there are about 60 unique travelers in use for SNS medium-β cryomodule production, which have been utilized over 1600 times.

Process Data Capture

In addition to process control, the electronic travelers described above also provide a means for easy and efficient process data capture. Accurate and timely capture of inspection, fabrication, and test data is vital to ensuring the integrity and accuracy of data later used in performance analysis and verification.

The travelers are designed to incorporate data fields to accept integer, floating point, and text data, along with direct upload of ASCII or binary data files. The data are then directly entered into an Ingres® database, and immediately available for review and analysis. The production facilities at JLab are equipped with wireless LAN transmitters, so that laptop PC's with wireless network cards can be utilized as mobile workstations to serve the online travelers.

Process Feedback

The electronic travelers provide almost real-time feedback to project staff. Data recorded by the travelers are immediately entered into the supporting database and are available for analysis. The general data field query mechanism of *Pansophy* allows production mangers and engineers to easily mine the traveler data to develop correlations between measured parameters and observed performance.

Furthermore, if a discrepancy is noted during an inspection, assembly, or testing process, a non-conformance report (NCR) can be launched from within the relevant traveler. This NCR is hyper-linked to the traveler, so that the responsible project staff can easily review the source of the NCR and dictate the appropriate corrective action. Once the project staff closes out the NCR, its initiator is notified automatically by e-mail of the disposition.

Sub-Assembly Test and Measurement

At various stages in the production cycle, acceptance testing is performed on sub-systems and larger components. This testing serves to ensure that complicated components that have already undergone significant handling, assembly, or fabrication, are able to meet their performance requirements. Since these systems, once installed in the cryomodule, are usually too complex or difficult to repair or re-configure in-situ, acceptance testing prior to further assembly provides an additional measure of confidence.

For example, before string assembly, all of the superconducting cavities are tested in the JLab Vertical Test Area (VTA) at 2K. Cavities that do not meet the required gradient and Q_o specifications are rejected, re-processed, and re-tested until adequate performance is achieved [4].

Likewise, the 1 MW power couplers are baked and RF conditioned to ensure that they will provide RF power at the required level and duty cycle without experiencing arcing or vacuum degradation. This conditioning also allows the performance of the coupler instrumentation to be assessed [5]. All couplers must pass this acceptance test before being released for use on a cryomodule.

As with other aspects of the SNS QA program, these tests are performed using electronic travelers that provide control of the test and measurement processes and procedures, and integration of the data with the *Pansophy* database.

Final Assembly Acceptance Testing

The ultimate performance verification of the SNS cryomodules is achieved through comprehensive cryogenic RF testing in the JLab Cryomodule Test Facility (CMTF). While cooling the SNS cryomodules to 2K, cryogenic performance and instrumentation is verified and recorded. Each cavity is then powered with the 1MW klystron and RF performance parameters such as gradient, Q_o, Lorentz force detuning, microphonics, HOM damping, etc. are determined and recorded [4].

Again, all test procedures and data are controlled and integrated using the online electronic traveler system.

Final acceptance of the cryomodules by the SNS is contingent upon a successful on-site inspection and verification, where the cryomodules are inspected for shipping damage, including analysis of accelerometer readings taken during shipment, and verification of instrumentation and vacuum system integrity, alignment, and fundamental cavity frequencies.

Document Control

The efforts to fabricate, assemble, and test a complex device such as a cryomodule with exacting performance requirements are necessarily driven by and dependant upon extensive documentation. Be they technical drawings or procedures, process control documents, statements of work, or test results, it is vital that accurate documentation be utilized at all times. Except for engineering drawings, version control and central archival of project documentation is achieved using the Docushare® document management system from Xerox. (Engineering drawings are managed by the JLab Accelerator Division's Mechanical Engineering Department's Document Control Group.) All documents, drawings, graphics, etc., that are hyperlinked to the electronic travelers are therefore managed such that modifications and revisions are uploaded following supervisory mechanisms.

Instrument, Device and System Calibration

Any QA program is only as good as the data that process control and engineering design decisions are based upon. Acknowledging this, the SRF Institute has required that instrumentation, devices, and systems that have been identified as process quality critical be in valid calibration status or removed from service. A tool has been developed as part of *Pansophy* that allows devices to be entered into a database, which tracks their calibration status, notifies the device or system owner when calibrations become due, and provides a means for requesting a device be sent out for calibration. Periodic audits are performed to ensure compliance.

In addition to instrumentation and devices, systems as a whole also are subject to calibration requirements. The RF test facilities are characterized by active and passive components, which can have an effect on measurement accuracy. Therefore, comprehensive calibration routines and procedures are carried out and documented before acceptance testing can begin.

QUALITY PROGRAM IN PRACTICE

While production is still at an early stage, the JLab SNS QA program has already been shown to be effective in several concrete ways.

In some instances, inspections of incoming components revealed lack of compliance with specifications, such as poor adhesion of copper plating on the Fundamental Power Coupler (FPC) outer conductors, incorrect bayonet heights on the cryomodule end cans, warping of the FPC inner conductor, and incorrect positions of the rings on the cryomodule space frame. Each of these issues were corrected by reviewing and revising the fabrication procedures and verification processes employed by the respective vendors.

Raw materials testing has likewise proven beneficial. Early mechanical tests of high-RRR Nb to be used in fabrication of cavities revealed that the hardness and elongation properties of both the as-received and post-heat treatment samples from one of the vendors did not meet the required specifications [6]. Closer analysis indicated that the material had not been fully re-crystallized due to incomplete annealing. The material was sent back to the vendor for re-annealing, and tested satisfactorily upon return. The vendor subsequently modified its annealing procedure.

As a result of the JLab component testing program, leak checking of the LN_2 circuits of the thermal shields eventually revealed leaks that had not been discovered by the vendor's own QA program. Discussions with the vendor and observations of their procedures led to improvements, which then yielded the required sensitivity and reliability. No leaks have been found subsequently.

Continued aggressive adherence to this QA program will prove to be vital in ensuring that the SNS linac project at JLab successfully fulfills its obligations in providing cryomodules that meet the required performance and reliability specifications while also accomplishing cost and schedule goals.

ACKNOWLEDGMENTS

Much as an Environment, Health, and Safety program does, an effective Quality Assurance program relies upon the active contributions of each participating individual. The SNS project at JLab has benefited from the dedicated efforts and cooperation of the staffs of the SRF Institute, Center for Advanced Studies of Accelerators, and Accelerator Division's Mechanical Engineering and Electrical Engineering Support departments. Their contributions are gratefully acknowledged.

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